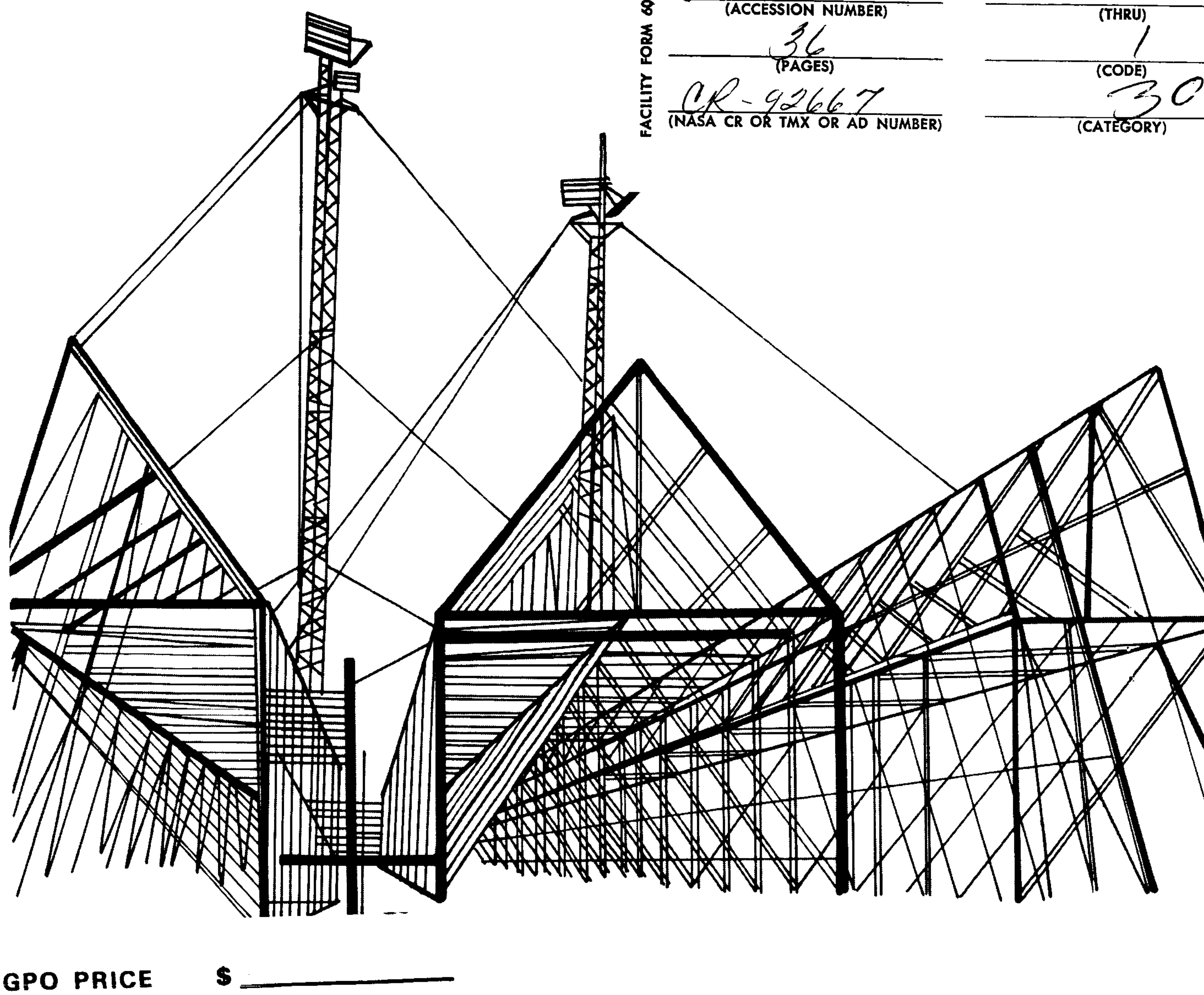
A COMPREHENSIVE STUDY OF THE CHARACTERISTICS OF METEOR ECHOES - I

G. S. HAWKINS and J. C. BROWN



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ABSTRACT

A system of classification of the shapes of meteor echoes is established, and a recording on punch cards of this classification with data on the meteors' physical properties is described. A simple velocity-computation method is described, and a number of statistical relations of shapes and physical properties are computed. The survey covers about 1000 meteors with a comprehensive study of all echo types. It shows some characteristics of the stations and selection effects in the established reduction program.

RÉSUMÉ

Un système de classification des formes d'échos des météores est établi, et un enregistrement sur cartes perforées de cette classification, avec les propriétés physiques des météores est décrit. Une méthode simple de calcul de vitesses est décrite, et nombre de relations statistiques sur la forme et les propriétés physiques ont été calculées. L'étude couvre environ 1000 météores, avec une analyse de tous les types d'échos. Elle montre quelques caractéristiques des stations, et des effets sélectifs dans le programme de réduction qui a été établi.

КОНСПЕКТ

Установлена система классификации форм отражений от метеорного следа, и описывается запись на напуншированные карточки этой классификации с данными физических свойств метеоров. Описывается простой метод вычисления скоростей и высчитывается число статистических отношений между формами и физическими свойствами. Обзор включает около 100 метеоров с всесторонним изучением всех типов отражений. Обзор указывает на несколько характеристик станций и влияний выбора в установленной программе преобразования.

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1. INTRODUCTION

The aim of this project was to augment the computations of the established reduction program by a comprehensive measurement of all echoes of all types on the six-station films. In particular, the shapes of the meteor echoes were classified and an attempt was made to relate these shapes statistically to the physical properties of the meteors. Information on theoretical echo shapes and computational methods was obtained from McKinley (1961) and Southworth (1962). The derived velocity distribution was compared to that obtained for ideal echoes as described by Baker (1963).

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2. OBSERVATIONAL MATERIAL

The material studied was a selection of films obtained in 1964 by the Harvard Radio Meteor Project, located at Havana, Illinois, with the six-station radar array (Hawkins, 1963). This system used a single-trough transmitting antenna emitting pulsed radar in the form of 6-μsec pulses at a rate of 739 pulses sec^{-1} and at a frequency of 40.92 mc sec^{-1}, and five remotely located Yagi receiving antennas all linked by a microwave system to the central receiving station where film recording was carried out. The films are essentially a recording of echo amplitude versus time for all six stations, together with a range recording for station 3, the transmitting station. It should be pointed out that the amplitude of the echo as recorded on film was not linearly related to the power received, nor was it equal in scale from one station to another. At all stages of this report, amplitude refers to recorded amplitude. Amplitude calibrations are recorded on all films, however, and true echo powers could be obtained by use of these calibrations if required for future reports.

In addition to the nonlinearity, the receiving equipment had two characteristics that proved of some importance in the investigation. First, the triggering arrangement of the system operated only for echoes above a fixed "bright-up" amplitude, which often resulted in omission of many pulses in small amplitude echoes. Second, the amplitude recording scales had a saturation amplitude that cut off the amplitude of many large amplitude echoes. Both these characteristics complicated shape classification of the echoes, to be described later in the report.

2.1 Selection of Films

A selection of 14 films was made to give fair coverage of the 24 hours of the day in the periods January, May-June, and October-November 1966. The film numbers, dates, and time limits of the measured sections are listed for each film in Table 1. The first 72 meteors were recorded on each film, giving a total of 1008 meteors.

Table 1. Details of selected films

Film number	Date (1964)	Time of first meteor measured	Time of last meteor
542 roll 1	January 1	08 07 48	08 15 19
545 roll 1	January 14	00 11 59	01 13 51
551 roll 4	January 29	11 13 38	11 59 43
572 roll 2	April 24	20 16 06	22 27 41
577 roll 1	May 8	16 44 51	18 52 17
579 roll 5	May 19	06 21 20	07 05 18
583 roll 2	June 1	02 01 47	02 09 22
584 roll 4	June 2	04 59 54	05 03 21
625 roll 2	October 7	09 02 37	09 08 06
627 roll 2	October 9	18 41 29	19 05 59
627 roll 4	October 9	22 28 07	23 02 07
630 roll 2	November 2	01 33 56	01 38 11
631 roll 3	November 3	03 12 52	03 17 34
632 roll 5	November 4	14 21 39	14 37 20

2.2 Measurement of Films

Since the survey was intended to cover the general form of all echoes recorded by the system, regardless of whether they conformed to theoretically computed forms, any echo that triggered the system was noted, except in a very few cases when a great deal of interference obscured the echo to the extent of rendering data on it useless. Such cases were rare, amounting to a total of less than 1% of all echoes.

The data recorded on the punch cards were chosen to give a reasonably accurate numerical categorization of the shape of the recorded echo and to provide as many data as possible on the measurements of the echoes that would contribute physical data on the meteor itself. Such data, e. g., velocity, range, time of day, could then be statistically correlated with the shape categorization.

Table 2 identifies the quantities in each column on the original punch cards. These data can be conveniently divided into two parts: the basic measurements of the size and shape of the echo, and a set of punched numbers indicating a rather involved note system. A detailed description of the basic data is given and the approximate column on the card is designated. This is followed by a similar description of the note system.

Table 2. Punch-card format summary

Column number	Data
1-12	Year, month, day, hour, minute, second
13	Blank
14	Range note
15-16	Range in 10-km units
17	Blank
18	Amplitude note
19-20	Maximum amplitude in 0.1 mm
21	Blank
22	Duration note
23-24	Duration in 0.1 mm
25	Blank
26	Zone number note
27-28	Number of zones at station 1
29-30	Number of zones at station 2
31-32	Number of zones at station 3
33-34	Number of zones at station 4
35-36	Number of zones at station 5
37-38	Number of zones at station 6
39	Blank
40	Zone separation note
41-42	Zone separation in 0.1 mm
43	Blank
44	Zone depth note
45-46	Zone depth in 0.1 mm
47	Blank
48	Shape category note
49-51	Shape categories at station 1
52-54	Shape categories at station 2
55-57	Shape categories at station 3
58-60	Shape categories at station 4
61-63	Shape categories at station 5
64-66	Shape categories at station 6
67	Blank
68	Rise length note
69-70	Rise length in 0.1 mm
71	Blank
72-76	Meteor number (if any)

3. BASIC MEASUREMENTS

The first data recorded for each meteor are the date and time of the echo, specified as a 12-digit number (year, month, day, hour, minute, second) in columns 1 to 12 of the card.

The range is estimated to the nearest 10 km in units of 10 km. This 2-digit number occupies columns 15 and 16. Cases where the range is ambiguous are put in the interval 70 to 270 km (the most probable range). The entry 00 indicates that no measurement was available.

The maximum amplitude, the largest amplitude reached by the echo at any point (e. g., see Figure 1 for maximum amplitude on a Fresnel echo), is measured in units of 0.1 mm to the nearest 0.1 mm and specified as a 2-digit number in columns 19 and 20. (In Figures 1 and 2* the time axis is drawn reversed to correspond to the appearance of the film record, and facilitates a comparison of these classification diagrams with subsequent film records.)

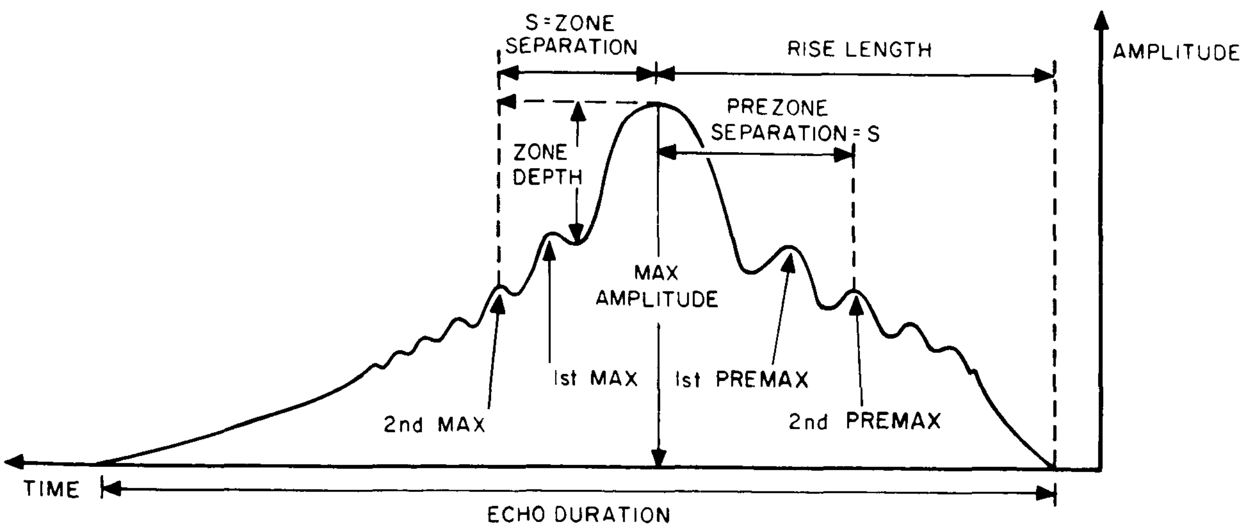

Figure 1. Fresnel-echo notation.

*See Section 5.

The duration of the echo, distance from start to finish along the time axis, is also measured as a 2-digit number in units of 0.1 mm and occupies columns 23 and 24. This measurement can be readily translated into an actual time as described later in Section 6.

Most ideal echoes, i.e., echoes of the theoretical form for an ionized column, have Fresnel zones only after the minimum range point. These echoes show a maximum in the signal, followed by subsidiary maxima. A few echoes, less than 5%, have zones before the maximum (theoretically predicted for a nonuniformly ionized column) and are shown in Figure 1. They will be referred to as having premaxima. The notations 1st maximum, 2nd maximum, etc., and 1st premaximum, 2nd premaximum, etc., will be used to describe successive maxima after and before the main maximum, respectively. The main maximum is regarded as zero. The notation is indicated in Figure 1.

The number of Fresnel maxima visible is counted at each station (a 2-digit number) and written as a 12-digit number for successive stations 1 through 6 in columns 27 to 38. This number is strictly the number of maxima and does not include premaxima.

The zone separation gives an estimate of the meteor velocity (see Section 6) and is measured as the distance along the time axis from the main maximum to the 2nd maximum (see Figure 1) in units of 0.1 mm, giving a 2-digit number in columns 41 and 42. The entry 00 indicates that no measurement was possible. (When only the 1st maximum was visible, the measurement punched was 1.6 times the separation of the 1st maximum from the main maximum.)

Theory shows that the prezones are equivalent to the zones for computing velocity measurement. Thus, in cases where prezones are present without zones, the separation of the 2nd premaximum from the main maximum is measured.

The zone depth is measured as the depth, in units of 0.1 mm, of the 1st minimum after maximum amplitude below the maximum amplitude point (see Figure 1). Again, this is a 2-digit number, in columns 45 and 46. This measurement is made in order to estimate, from the theory of the diffusion of the ionized column (Loewenthal, 1956; Brysk, 1958), the height of the meteor.

The shape of the echo is determined by dividing the echo into three parts — designated rise, middle, and fall. In cases where no distinctive rise, middle, and fall are visible, the echo is arbitrarily divided into three equal parts and these are placed as nearly as possible in the established categories. For each section (rise, middle, and fall), 10 shape categories 0 to 9 are established. The system of categories is fully described later with accompanying diagrams. The shape is specified at all six stations in turn, a 3-digit number specifying each one. The resulting 18-digit number occupies columns 49-66.

The length of rise is also measured in order to give quantitatively the rate at which the echo rises to maximum amplitude (see Figure 1), in addition to the qualitative shape specification. It is measured in units of 0.1 mm and specified as a 2-digit number in columns 69 and 70.

The meteor number as ascribed in previous reduction work is added to the data for comparison of the "ideal" meteors with those of the general survey. Since only 17 reduced meteors were found in the 1008 measured, the majority have no meteor number and 00000 is punched in columns 72 to 76, where meteor numbers are recorded.

4. THE NOTE SYSTEM

This system specifies any peculiarities of the echoes or any special aspects of any measurement requiring special treatment. Notes are used for the various quantities and the symbols "1", "0", "-" are given to each of them; their meaning and usage are explained below.

4.1 Range Note

This is either a "0" or a "1" punched in column 14. If a "0" is punched, the range measurement following it is unambiguous. If a "1" is punched, the range measurement punched after it is such that the ranging system gives an ambiguous result, i.e., for example, a range could be 80 km, 280 km, 480 km, etc. In all such cases, the range measurement punched is that in the most probable range interval 70 to 270 km, the "1" indicating the ambiguity.

4.2 Amplitude Note

In this case a "0" indicates that the maximum amplitude was directly measured at station 3. In some cases, however, the maximum amplitude point was not recorded at station 3 (e.g., see Figure 2 A.0 in Section 5). In these cases, if the amplitude could not be measured or estimated for station 3, the maximum amplitude was measured at a station that had an echo most similar to that part visible at station 3 or was judged best under the circumstances. Such measurements are preceded by a "1" in column 18. A third possibility is that the maximum was not measurable at any station owing to saturation or delayed triggering. For these echoes, only a lower limit could be set to the amplitude measurement, and when this was done the "-" sign was punched in column 18. A saturation echo appears as -55 in the amplitude columns, since 5.5 mm was approximately the saturation amplitude. When a "-" precedes any number less than 55, the maximum has generally been omitted by delayed triggering, as shown in Figure 2 A.0. (When a station other than 3 was measured, the station actually used was noted along side the meteor time on the record sheet.)

4.3 Duration Note

This system is identical to that in the amplitude note, namely, "0" = measured at station 3, "1" = measured at a station other than 3, and "-" indicates a lower bound, generally owing here to cutoff by triggering. The measurements of duration, amplitude, zone separation and depth, and rise length are made only for the station (regardless of the number of stations with a recorded echo) with the most complete echo and with the clearest zones. This note symbol is punched in column 22. Because only a 2-digit number is allocated here, any echo longer than 9.9 mm is recorded as -99.

4.4 Zone Number Note

A "1" in column 26 indicates that zones were just visible at saturation amplitude but not distinct enough to be counted with certainty.

4.5 Zone Separation Note

In column 40, a "0" indicates measurement at station 3. Here "1" may indicate, as above, that measurement was made at a station other than 3, but it is also used to indicate echoes where prezones rather than zones were measured. The prezone echoes can be distinguished by the additional category "5-rise." A "-" indicates a lower bound, sometimes yielding the result -99, owing again to the 2-digit limitation of the scale to 9.9 mm.

4.6 Zone Depth Note

The notation in column 44 is the same as that used for zone separation (column 40).

4.7 Shape Note

As in column 26, this note column 48 is rarely used and is not directly relevant to the reduction. In most cases, therefore, it is "0"; a "1" indicates that some peculiarity of shape categorization was noted on the record sheet, such as difficulty of classification due to noise or interference.

4.8 Rise Length Note

The notation in column 68 is the same as that for column 40.

It can thus be seen that the usage of "0" and "1" does not add quantitatively to the data measured, but, in general, a "0" preceding a piece of data indicates that it is more reliable for comparison with other echoes than if a "1" were used. For example, in the calculation of velocity, certain approximations can be made that are best if station 3 is used for all measurements. The use of the "-" is, of course, essential to distinguish actual measurements from lower bounds.

5. SHAPE CLASSIFICATION CATEGORIES (See Figure 2)

A. Rise Shape

Category 0 (A.0) The rise of the echo is completely cut off the record by late triggering, or, if for some other reason, no "rise" can be defined on the echo. This category is also used when an echo is so small and short that only a middle category can reasonably be ascribed. It is not used when only part of the rise is cut off (see A.4).

Category 1 (A.1) The shape of rise is similar to that of an ideal theoretical Fresnel pattern for a uniformly ionized column, viz., a short steep-rise convex toward increasing time on the recording scale.

Category 2 (A.2) The rise is short, as in A.1, but entirely concave toward increasing time.

Category 3 (A.3) This is the same as A.1 and A.2 but with a straight rise.

Category 4 (A.4) This is similar to A.0 but applies to cases where the last part of the rise was recorded, only the first part being cut off by the triggering time. It also applies when rise occurs in a step for any reason other than triggering.

Category 5 (A.5) The rise shape is similar to that for an ideal theoretical Fresnel echo from a nonuniformly ionized column, having zones before the maximum amplitude (prezones).

Category 6 (A.6) This is similar to A.3 but for long straight rises (i.e., gentle slope).

Category 7 (A.7) This long slow rise occurs as a series of steps.

Category 8 (A.8) The long slow rise shows long-period fluctuations characteristic of a "wind-blown" meteor trail.

Category 9 (A. 9) This category is used for echoes of small, nearly constant amplitude close to the minimum bright-up amplitude.

B. Middle Shape

Category 0 (B. 0) Triggering was so late that only the end of the echo was recorded, rise and middle being omitted, or when only the rise was recorded before cutoff.

Category 1 (B. 1) The echo shape resembles that of the theoretical Fresnel echo-slow falloff with Fresnel zones.

Category 2 (B. 2) This is similar to B. 1 in shape but with no zones.

Category 3 (B. 3) A fairly large constant amplitude shows irregular small fluctuations superimposed.

Category 4 (B. 4) The shape is similar to B. 3 but with no fluctuation, for example, a middle at saturation amplitude. If, however, the saturation occurs only at the start of the middle, leaving sufficient unsaturated to identify the true shape, then the true shape category is punched, not the saturation category.

Category 5 (B. 5) A steep step-down after the rise is followed by a slow falloff.

Category 6 (B. 6) This is similar to B. 2 but has a step-up before final falloff.

Category 7 (B. 7) The properties of B. 5 and B. 6 are here combined.

Category 8 (B. 8) This corresponds to A. 8, i. e., typical wind-blown long-period fluctuating echoes.

Category 9 (B. 9) This corresponds to A. 9, i. e., small, near-constant amplitude echoes.

C. Fall Shape

Category 0 (C. 0) Falloff is interrupted by cutoff and the fall is omitted or cannot be defined for some other reason.

Category 1 (C. 1) Start of fall has Fresnel zones and the end falls off smoothly to zero amplitude (ideal theoretical echo).

Category 2 (C. 2) This is like C. 1 but with no zones.

Category 3 (C. 3) This category corresponds to A. 8 and B. 8, i. e., a long slow fall-off with long-period fluctuations of "wind-blown" type.

Category 4 (C. 4) This corresponds to A. 4. It is applied when only part of the fall is cut off (not omitted as in C. 0) or when any step fall occurs.

Category 5 (C. 5) The steep and abrupt fall is concave toward increasing time.

Category 6 (C. 6) This is similar to C. 5 but convex toward increasing time.

Category 7 (C. 7) The falloff tapers to a very small, nearly constant amplitude around bright-up or it can be applied to echoes where the amplitude is small throughout. (A Fresnel-type echo often ended as C. 7 rather than C. 1.)

Category 8 (C. 8) This is similar to C. 5 and C. 6 but has a steep straight slope for the fall.

Category 9 (C. 9) A steep step-down from the middle is followed by a prolonged end of small, nearly constant amplitude.

RISE SHAPES

A. 0 Rise Completely Cut Off

A. 1 Short Concave Rise

A. 2 Short Convex Rise

A. 3 Short Straight Rise

A. 4 Rise Partially Cut Off by Triggering or Otherwise

A. 5 Fresnel-Zoned Rise

A. 6 Long Straight Rise

A. 7 Stepped Rise

A. 8 "Wind-Blown" Rise

A. 9 Very Small-Amplitude "Rise"

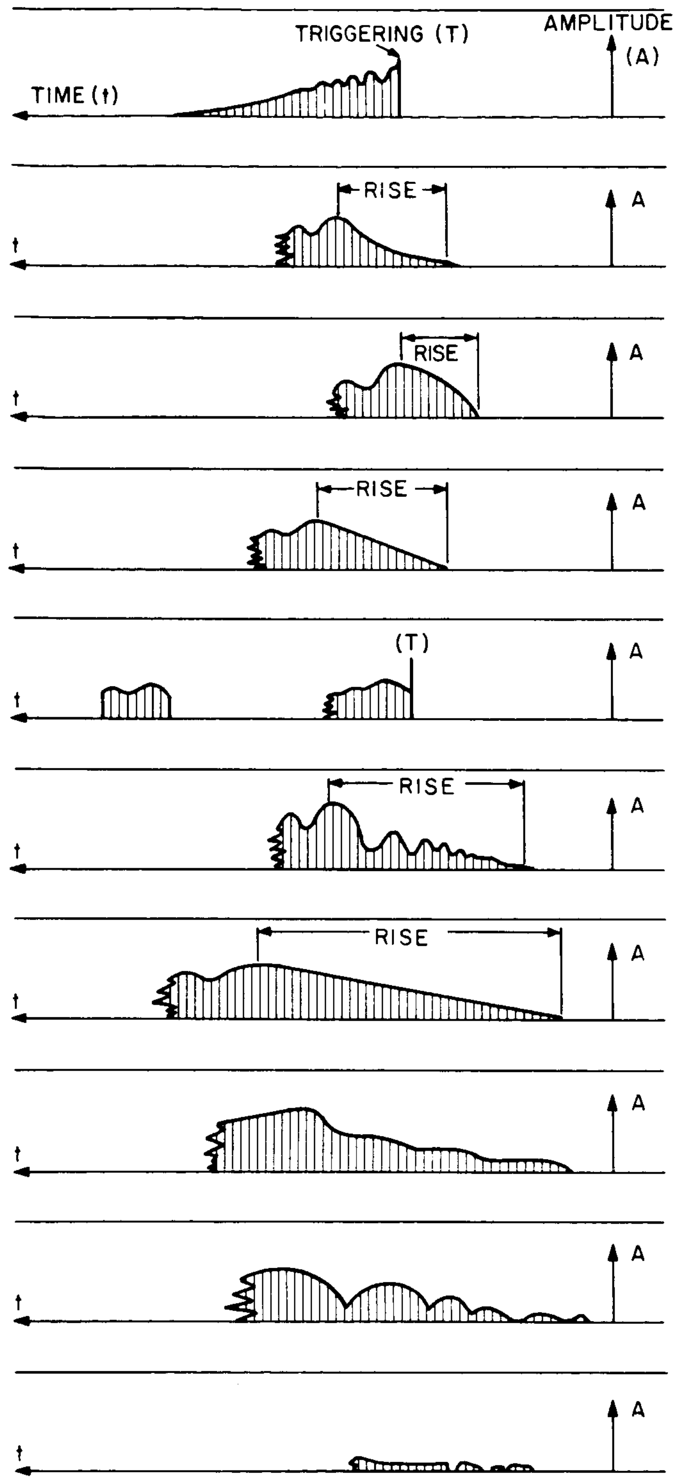

Figure 2. Shape classification categories.

MIDDLE SHAPES

B. 0 Middle Cut Off by Triggering or by Early Cutoff

B. 1 Slow Fall-Off with Fresnel Zones

B. 2 Slow Straight Fall-Off

B. 3 Near-Constant Amplitude with Small Fluctuations

B. 4 Constant Amplitude No Fluctuations

B. 5 Step-Down Followed by Slow Fall-Off

B. 6 Slow Fall-Off with Steep Rise before Final Fall

B. 7 Combination of B. 6 and B. 7

B. 8 "Wind-Blown" Fluctuations

B. 9 Very Small-Amplitude Echo

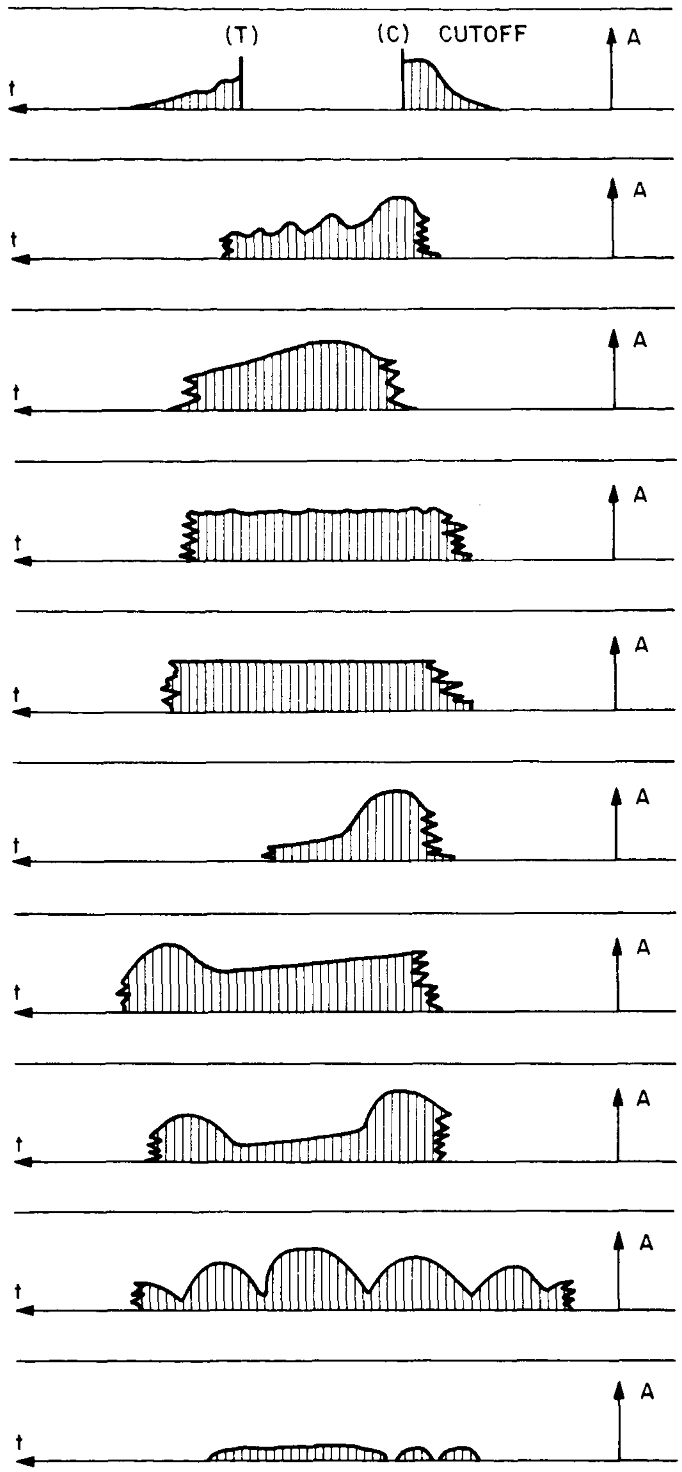

Figure 2 (Cont.)

FALL SHAPES

C.0 Fall Omitted Due to Cutoff

C.1 Slow Fall-Off with No Zones

C.2 Slow Fall-Off with No Zones

C.3 Long, Slow, "Wind Blown," Fall-Off

C.4 Fall-Off Interrupted by Cutoff

C.5 Short Concave Fall

C.6 Short Convex Fall

C.7 Prolonged Small-Amplitude "Fall"

C.8 Short Straight Fall

C.9 Step Fall Followed by Small-Amplitude Region

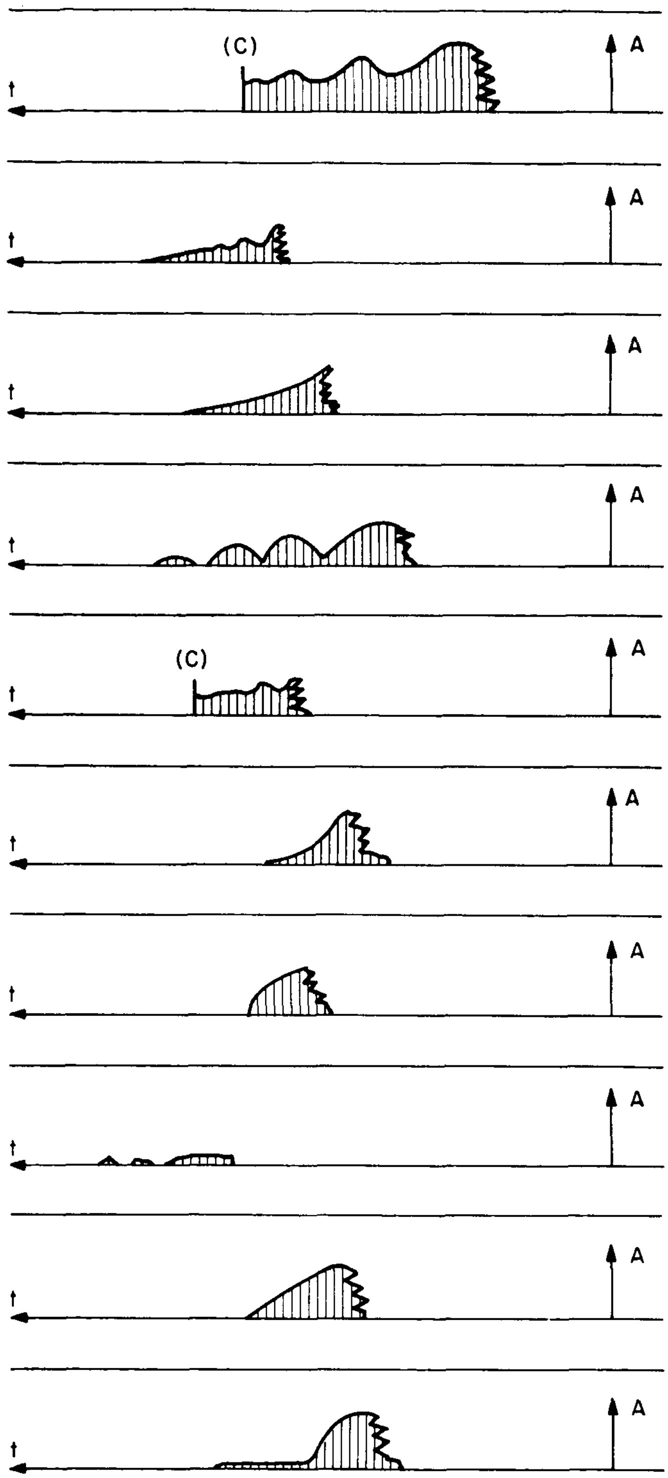

Figure 2 (Cont.)

6. VELOCITY COMPUTATION FROM THE DATA

For this investigation, only an approximate value is required for the velocity of any given meteor, to within ±5 km sec^{-1}, in order to compare the statistics of these velocities with other parameters such as shape. Thus, an approximate method is sought and the velocities finally are computed using the zone separation and the range measurements. The method does not, of course, apply unless at least two maxima are visible but nevertheless gives sufficient data for a preliminary study and covers a much wider selection of meteors than previous precise reductions.

The formula actually used is strictly correct only for all measurements made at station 3, but holds, to a good approximation, for measurements at other stations.

McKinley (1961, p. 204) shows that the time T taken by the meteor to travel from the point of maximum echo amplitude to the point corresponding to the 2nd maximum (or premaximum) of the Fresnel pattern (points A and B in Figure 3) is given by

$$T = \frac{(R_0 \lambda/2)^{1/2}}{V} \quad , \tag{1}$$

where R_0 is the minimum range, V the meteor velocity, and λ the radar wavelength (all in mks). Thus,

$$V = \frac{(R_0 \lambda/2)^{1/2}}{T} \tag{2}$$

provides the velocity measurement once T has been determined; T is determined from the zone separation measurement since the number of pulses per millimeter of film and the number of pulses per second are known. If the zone separation is given in units of 0.1 mm (as on the card) and denoted by S and if R_0 is given in units of 10 km and denoted by R, then, with all appropriate substitutions made for the system parameters, the formula

$$V = 500 \frac{(R/2)^{1/2}}{S} \tag{3}$$

is obtained (rounding error less than 1%). This gives V directly in km sec^{-1}.

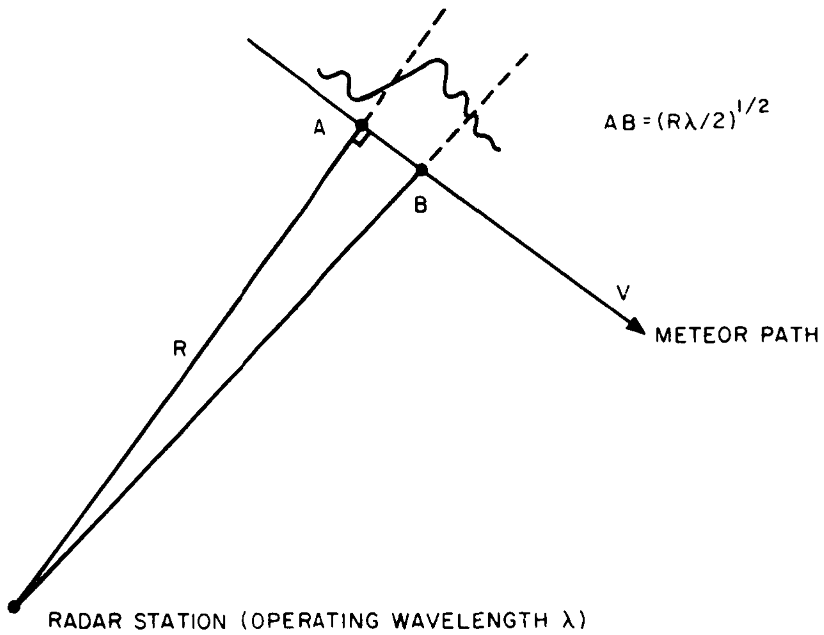

Figure 3. Relation of meteor path to the form of the echo.

The validity of this equation could not be checked for the poor echoes, since these had never been handled before, but computations were carried out for the 17 meteors that had been reduced, and the results are found to be in good agreement. For comparison, the meteor number, time of occurrence, range, and velocity according to the original reduction and also from the data for this report are tabulated for these 17 meteors in Table 3.

Table 3. Comparison of reduced meteor data with data for this report

Meteor number	Time of day		Range (km)		Velocity (km sec^{-1})	
	Reduced	Report data	Reduced	Report data	Reduced	Report data
14793	11 15 05	11 15 04	144.0	150	29.60	29
15627	21 13 40	21 13 25	139.9	150	12.27	14
15845	07 04 17	07 04 14	148.2	160	18.14	20
15846	07 04 53	07 04 52	173.9	180	58.25	61
15970	02 07 15	02 07 12	166.4	180	27.66	26
15971	02 09 16	02 09 15	266.9	240	30.74	27
16052	04 59 56	04 59 56	152.7	160	33.93	32
16053	05 01 28	05 01 23	183.6	190	35.51	37
16054	05 01 35	05 01 32	144.3	150	32.24	34
16055	05 03 51	05 03 50	527.4	520	45.14	48
17988	09 03 10	09 03 08	148.7	150	46.63	47
17989	09 03 41	09 03 41	174.6	180	52.99	52
17990	09 05 27	09 05 26	174.8	190	45.61	44
17991	09 05 37	09 05 36	377.1	190	77.96	55
18255	01 33 52	01 33 45	169.5	190	17.98	20
18477	14 30 53	14 30 49	148.1	160	30.28	31
18478	14 37 17	14 37 09	165.4	170	38.98	39

This table shows clearly that the above method for velocity measurement is sufficiently accurate (±5 km sec^{-1}) for the purposes of this report for reduced meteors.* The data obtained (see Section 8.3) are in good agreement with previous work and show no irregularities, so this method appears adequately justified even for meteors not previously reduced. (The film measurements should give a velocity with an error of about ±10%, neglecting theoretical approximations.)

*The one exception to this statement is meteor number 17991, the velocity of which was originally reduced as 77.96 km sec^{-1}. When the film was rechecked, however, it appeared that the original range measurement was wrong, the range scale being rather unclear. A range of 177 km instead of 377 km gives the more probable velocity of around 55 km sec^{-1}.

7. REDUCTION

For this report, only some of the preliminary statistical data were computed, by no means encompassing the scope of all the data punched on the cards. Even these, however, are of considerable interest and show the value of handling meteor echoes in this way, though preferably in much greater numbers. In particular, the following statistical data were computed.

7.1 Statistical Distribution of Shapes

This was computed as a simple listing of the number of meteors having rise categories 0 through 9 for each of stations 1 to 6 in turn, and, similarly for middle categories 0 through 9 and for fall categories 0 through 9. The results are tabulated as a 10×18 array in Table 4. The total number of each rise, middle, and fall type for all stations together was also computed and tabulated in Table 4.

7.2 Statistics of Station Recording

The number of meteors recorded by each station was also computed in order to compare the relative recording rates of the six stations. These results are tabulated in Table 5.

7.3 Velocity Distribution

Velocities were calculated for all meteors having both range and zone measurements. The number of meteors in ranges 0 to 5 km sec^{-1}, 5 to 10 km sec^{-1}, $\cdots$, 75 to 80 km sec^{-1} were computed and tabulated. The total number of computed velocities was 274 (27% of all echoes recorded). Five of these were found to have measured velocities greater than 80 km sec^{-1}. A further 31 were classed as "slow." This term was applied to meteors for which the zone separation "5" had only been set as a lower bound (i. e., with

Table 4. Shape frequency statistics

Station number	Part	Frequency									
		1	2	3	4	5	6	7	8	9	10
1	Rise	12	38	20	84	18	5	1	18	32	778
1	Middle	81	43	66	11	1	2	0	40	62	700
1	Fall	12	26	35	72	2	1	133	1	2	722
2	Rise	40	48	46	76	25	6	1	21	50	693
2	Middle	135	42	46	9	3	1	0	53	95	622
2	Fall	27	41	42	44	2	2	188	2	4	654
3	Rise	88	57	74	84	38	7	1	21	108	528
3	Middle	218	54	43	16	5	1	0	63	207	399
3	Fall	60	41	52	38	3	5	337	2	7	461
4	Rise	94	43	71	73	31	9	2	27	117	539
4	Middle	197	56	49	3	3	1	0	73	166	458
4	Fall	39	41	52	31	5	4	333	2	6	493
5	Rise	109	52	81	77	38	6	0	28	158	457
5	Middle	213	72	52	14	7	1	1	79	234	333
5	Fall	44	50	61	36	5	2	447	1	7	353
6	Rise	38	69	77	62	29	6	1	27	52	645
6	Middle	137	64	68	13	6	0	0	64	68	586
6	Fall	26	40	36	76	3	5	152	1	2	665
Data for all stations											
Total rise		381	307	369	456	179	39	6	142	517	3640
Total middle		981	331	324	66	25	6	1	372	832	3098
Total fall		208	239	278	297	20	19	1590	9	28	3348

Table 5. Station recording statistics

Station number	Number of meteors recorded	Percentage of total
1	333	33.8
2	412	41.0
3	639	63.5
4	589	58.6
5	725	72.1
6	436	43.5

a "-" in the note column). Thus only an upper limit could be set to their velocities. The meaning of "slow" is thus a function of the meteor range. The upper limit corresponding to a selection of ranges is tabulated below:

Range (km)	40	80	120	160	200	240	280	320	360	400
Upper velocity limit (km sec^{-1}) (for a slow meteor)	7.0	10.0	12.3	14.1	15.8	17.3	18.7	20.0	21.2	22.4

The results are shown in Table 6 and the normalized distribution in Figure 4.

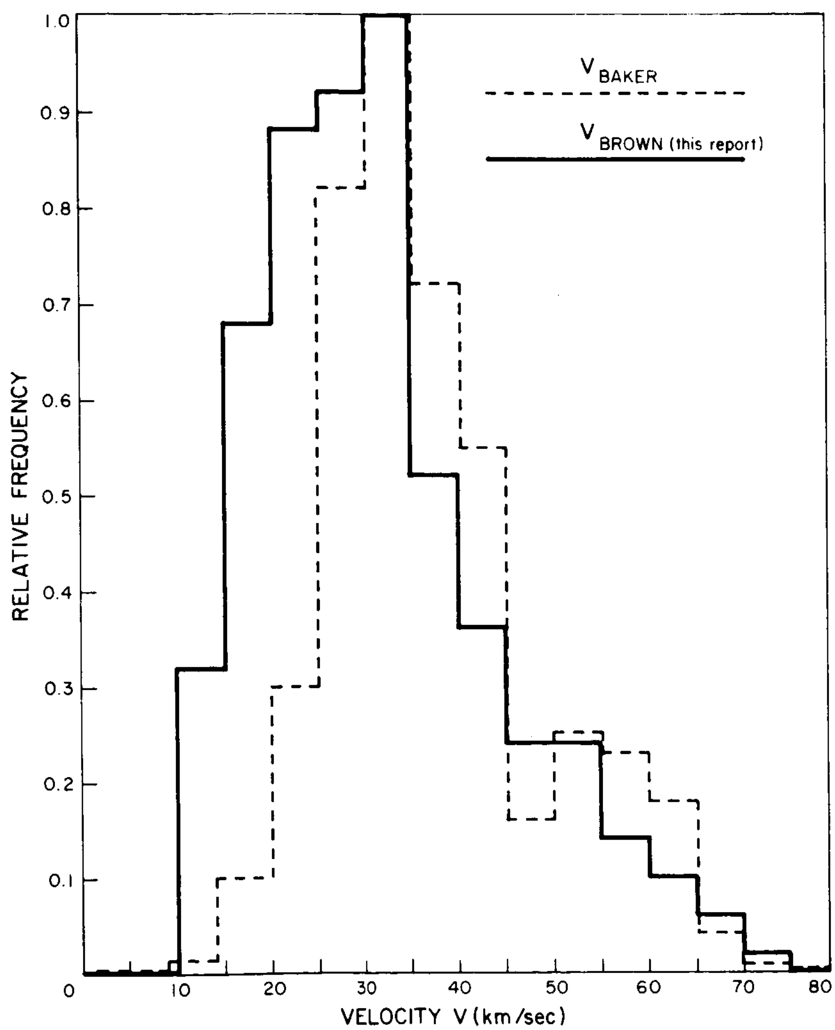

Figure 4. Relative velocity distribution.

Table 6. Velocity-distribution data

Velocity range (km sec^{-1})	Meteor count	Percentage of good echoes at each station					
		Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
0-5	0	—	—	—	—	—	—
5-10	0	—	—	—	—	—	—
10-15	16	0	12.5	18.8	12.5	12.5	0
15-20	34	0	0	8.8	8.8	8.8	0.3
20-25	44	2.3	0	6.8	9.1	6.8	2.
25-30	46	0	2.2	15.2	19.6	28.3	4.4
30-35	50	0	6.0	14.0	20.0	30.0	6.0
35-40	26	3.9	11.5	26.9	19.2	38.5	0
40-45	18	5.6	0	11.1	16.7	0	5.6
45-50	12	0	16.7	33.3	41.7	16.7	8.3
50-55	12	0	8.3	16.8	16.7	25.0	0
55-60	7	14.3	0	14.3	28.6	0	0
60-65	5	0	0	20.0	0	0	0
65-70	3	0	0	66.7	0	33.3	33.3
70-75	1	0	0	0	0	0	0
85-80	0	—	—	—	—	—	—

Total number of echoes with velocity computed = 274 = 27% of total number of echoes recorded.

Number of "slow" meteors = 31 (see Section 7.3 for explanation).

Number of meteors with measured velocity over 80 km sec^{-1} = 5.

8. DISCUSSION

8.1 Station Recording Statistics

Table 5 shows a clear rise in the recording rate of stations 1 to 5, with a falloff for station 6. The configuration of the antenna system was such that stations 1, 2, 3, etc., also most frequently triggered that sequence. Thus, meteors were at greater heights when in a position to trigger the earlier stations. Being at a lower height when in a position for triggering the later stations, and being more likely to cause triggering at lower heights, the majority of meteors predominantly triggered later stations, reaching maximum rate for station 5.

8.2 Shape Distribution

Table 4 contains a great deal of information on both the recording characteristics of the stations and the occurrence rates of the shape categories themselves.

Most interesting of all are the nearly ideal echoes. A truly ideal echo is represented by "111" on the punch card, but most often the fall tails off more slowly and the combination "117" can be considered nearly ideal. If only the strictly concave rise (A. 1) is considered ideal, then about 12% of the useful echoes are ideal in the rise. If the similar rises A. 2 and A. 3 (convex and straight) are included, then this figure becomes about 30%. The middle portion of an ideal echo is, however, of greatest interest as it is here that zone measurements are made. Also from Table 4 it can be seen that about 30% of useful echoes have the category B. 1 (i. e., 15% of the total). This figure gives a measure of the probability of any echo (treating different stations as separate echoes) having measurable zones, but it is an optimistic estimate since some of the zoned echoes may all be from one meteor but on different stations. Nevertheless, of the total 1000 echoes, the velocities of 274 were measured, i. e., about 30%.

It is of special interest to recall that only 17 (2%) of these had been previously reduced. This is due to the more stringent criteria used for reduction than for this report. For the full reduction, good echoes from a meteor must be recorded on at least three stations. If the probability for each station is about 1/3 (30%), then the probability of three stations recording zones should be of the order of $1/3 \times 1/3 \times 1/3$, i.e., about 3%. Thus the two sets of facts are in agreement.

In general, the "0"-shape category indicates that an echo was unobservable because of late triggering or a premature cutoff of the recording system. This, in effect, means a technical failure in the recording system and loss of information. Approximately 5% of the sample were in this category either in the rise, middle, or fall portion of the echo.

Echoes in the categories A. 9, B. 9, and C. 7 with short duration are produced by meteors on the threshhold of detection of the system. Approximately 10% of the sample were at this limit.

8.3 Velocity Distribution

Figure 4 shows the relative velocity distribution for about 850 meteors obtained by Baker (1963), and for 274 meteors obtained in this report. The agreement is good, especially for the maximum of the distribution at 30 to 35 km sec^{-1}. This report shows an increase in the low-velocity component.

It should be borne in mind that the data for this report were not weighted in any way to eliminate selective effects in the choice of films, either in time of day or time of year. In fact, meteor showers intrude into some of the data. Baker has taken both of these effects into account.

8.4 Range Distribution

A simple table of number of meteors with ranges in 20-km increments from 0 to 600 km was computed and is reproduced in Table 7. These results became available just before publication of the report, and no detailed examination was made of them. The maxima that appeared in the distribution at 150 km, 400 km, and 530 km are, however, not characteristic of the meteors but of the recording system whose lobes select meteors preferentially in range. Close examination of this table would provide information on the antenna lobe pattern.

8.5 Good Echo-Velocity Relationship

Another set of results obtained at the closing of this report was a tabulation of the number of good echoes falling into each velocity range. This was computed for each station separately and is recorded as part of Table 6, which gives the number of good meteors in velocity intervals of 0 to 5, 5 to 10, 10 to 15, $\cdots$, 75 to 80 km sec^{-1} (a good meteor appears as "111" or "117" on the cards). These numbers are also given as percentages of the total number of meteors in the velocity increment.

Study of Table 6 should provide information on the dependence on velocity of the production of ideal echoes. A similar correlation with range replacing velocity is the projected next set of results.

The above correlations and deductions are of a preliminary nature. Clearly, the data should receive a more extensive study than they were given in this report, especially once a larger sample has been obtained.

Table 7. Range distribution (total measured = 663)

Range interval (km)	Number of meteors	% of total
0-20	0	0
20-40	0	0
40-60	0	0
60-80	0	0
80-100	2	0.3
100-120	12	1.8
120-140	70	10.5
140-160	186	28.1
160-180	131	19.8
180-200	103	17.5
200-220	8	1.2
220-240	20	3.0
240-260	25	3.6
260-280	15	2.3
280-300	24	3.6
300-320	8	1.2
320-340	8	1.2
340-360	10	1.5
360-380	1	0.15
380-400	1	0.15
400-420	1	0.15
420-440	7	1.05
440-460	5	0.75
460-480	3	0.45
480-500	0	0
500-520	1	0.15
520-540	2	0.3
540-560	8	1.2
560-580	1	0.15
580-600	1	0.15

Number of meteors with no measured range = 342.

Number of meteors outside above range (i.e., >600) = 1.

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BIOGRAPHICAL NOTES

DR. GERALD S. HAWKINS is an astronomer on the staff of the Smithsonian Astrophysical Observatory, and holds joint Harvard appointments as Research Fellow at the Harvard College Observatory and Research Associate at Harvard University. He is also the Chairman of the Boston University Department of Astronomy and is the Director of that University's observatory.

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